

Free Energy

Where does the energy come from that keeps all living things alive?

Why?

All living things require a constant flow of energy. This is one of the big ideas in science. If the flow of energy to an ecosystem is cut-off, like an extended lack of sunlight or food, then all the living things in the ecosystem will die. But you have heard of the Law of Conservation of Energy, so why wouldn't there always be enough energy to go around?

Model 1 – Spontaneous Processes

	Process Description	Change in Enthalpy (ΔH)	Change in Entropy (ΔS)	Spontaneous?
A	Two pure substances \rightarrow Homogeneous mixture	~ 0	Increasing	Yes
B	Solute on one side of membrane \rightarrow Solute on both sides of membrane	~ 0	Increasing	Yes
C	Polypeptide chain \rightarrow Individual amino acids	Exothermic (negative)	Increasing (positive)	Yes
D	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$	Exothermic	Increasing	Yes
E	$6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$	Endothermic	Decreasing	No
F	Glucose \rightarrow Starch	Endothermic	Decreasing	No
G	Water \rightarrow Ice	Exothermic	Decreasing	Below 0 °C, yes Above 0 °C, no
H	Cold water (25 °C) \rightarrow Hot water (60 °C)	Endothermic	Increasing	Below 60 °C, no Above 60 °C, yes

1. Consider Model 1.

- What two terms are used to describe the enthalpy changes for the reactions?
- What is the symbol for the change in enthalpy?
- What sign (+ or –) does the change in enthalpy have when the reaction releases heat energy to the surroundings?

2. Refer to Model 1. For each process below indicate if the change would be endothermic or exothermic.
 - a. A plant making glucose from carbon dioxide and water.
 - b. An ice cube melting.
 - c. Amino acids forming a polypeptide chain.

Read This!

The net energy change for a reaction is related to the strength and number of bonds that are broken and formed during the reaction. Breaking bonds requires energy while forming bonds releases energy. If more or stronger bonds are formed than are broken, then the reaction will be **exergonic** (a net release of energy will be observed). If more or stronger bonds are broken than are formed, then the reaction will be **endergonic** (a net absorption of energy will be observed).



3. According to Model 1, are all exothermic reactions spontaneous? If no, provide a counter example from Model 1.



4. Consider Model 1.
 - a. What is the symbol for the change in entropy of a system?
 - b. When the entropy of a system increases, what sign (+ or −) is used?
5. According to Model 1, is there a correlation between the change in enthalpy and the change in entropy for a system? If yes, describe the correlation.
6. Refer to Model 1. For each process below indicate if the entropy would increase or decrease.
 - a. Food coloring mixing into water.
 - b. A hot substance cooling to room temperature.
 - c. The respiration of glucose and oxygen to produce carbon dioxide and water.

7. For each of the processes in Model 1, decide as a group if the molecules in the substances have more order (are more organized) before or after the reaction. Circle the side of the reaction with more order.
8. Is there a correlation between the level of organization in the molecules and a change in entropy according to the examples in Model 1? Justify your reasoning.



Read This!

The **entropy** of a system can be thought of as a measurement of the amount of disorder in the molecules that make up the system. The study of entropy is based in statistics. There are only a few ways in which a system can be organized and have low entropy, but there are usually many more ways in which a system can be disorganized and have high entropy. Therefore, systems are more likely to exist in higher entropy states. Just think of your bedroom at home. If you do not spend energy to clean it, is it likely to be organized or disorganized?

9. Predict if the following processes would have an increase in entropy or a decrease in entropy based on what you have learned from Model 1.
 - a. Water evaporating from a wet sidewalk.
 - b. Separating a mixture into pure substances.
 - c. A plant using raw materials to build a leaf in the spring.
 - d. Leaves decomposing in winter.



10. Is an increase in the entropy of a system sufficient to make a process spontaneous? Justify your reasoning with evidence from Model 1.

Read This!

Some of the processes in Model 1 are **spontaneous**—that is, they will occur without any additional work being done on the system. For example, a solute will diffuse across a membrane until the concentrations of both sides are equal. However, glucose will not spontaneously form from carbon dioxide and water in the atmosphere. The **Second Law of Thermodynamics** states that a process will be spontaneous when it results in an increase of *total entropy* in the universe. In other words, either the system or the surroundings must have an increase in entropy, or both.

(Please note that the term “spontaneous” does not imply that the change will happen quickly. Rusting is spontaneous under the right conditions, but it can still occur very slowly.)

11. Consider the exothermic reactions in Model 1. When those reactions occur what typically happens to the temperature of the surroundings?



12. Predict the change in entropy of the surroundings for an exothermic reaction. *Hint:* Find a system that changed temperature in Model 1.

13. Predict the change in entropy of the surroundings for an endothermic reaction.

14. Provide the letter of at least one process from Model 1 that illustrates each of the following conditions that will result in a spontaneous reaction.
 - a. Both the system and surroundings have an increase in entropy.
 - b. The increase in entropy of the system exceeds the decrease in entropy of the surroundings.
 - c. The increase in entropy of the surroundings exceeds the decrease in entropy of the system.



Read This!

When a process is spontaneous it can be used to do work. For example, the respiration of glucose is used in organisms to run cellular processes like the production of enzymes. The amount of work that can be done by a spontaneous process is called **Gibbs Free Energy**, named after the mathematician that developed the concept in 1873. Josiah Willard Gibbs proposed the equation that scientists now use to calculate the free energy change for a process.

$$\Delta G = \Delta H - T\Delta S$$

When ΔG is negative, the process is spontaneous and can do work (**exergonic**). When ΔG is positive, the process is not spontaneous. Work must be done on the system to make it happen (**endergonic**). Note that the temperature in the equation is in Kelvin and will always be a positive number.

15. Consider process C in Model 1.

- a. Would the ΔH term in the Gibbs free energy equation be positive or negative?
- b. Would the ΔS term in the Gibbs free energy equation be positive or negative?
- c. Show how the change in enthalpy and entropy of process C in Model 1 would result in a spontaneous reaction at all temperatures.

16. Use the Gibbs free energy equation to show how the change in enthalpy and entropy of process E in Model 1 would not result in a spontaneous reaction.

17. Processes A and B in Model 1 have very minimal energy changes. Explain why those processes are spontaneous.

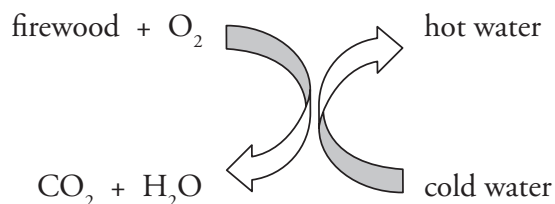
18. Consider process G in Model 1.

- What is the entropy change for the system?
- What is the entropy change for the surroundings?
- Which factor must be larger when the temperature is above 0 °C (273 K), the entropy change of the system or the entropy change of the surroundings? Explain your reasoning.

Read This!

In biological systems, exergonic processes are often coupled with endergonic processes. This is what allows for the great degree of organization that we see in organisms. The organisms are not violating the second Law of Thermodynamics. Rather, they are leaving a wake of disorder around them as they eat, breathe, and grow.

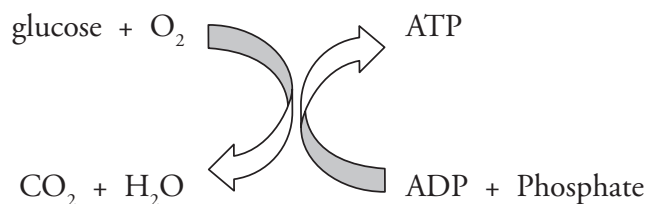
19. If you have ever been camping, you may have used coupled processes to make yourself some hot cocoa in the evening.



- Which of the processes above is exergonic, and does work?
- Which of the processes above is endergonic, and has work done to it?



20. Consider the coupled processes below.



- Which of the processes above is exergonic, and does work?
- Which of the processes above is endergonic, and has work done to it?



Extension Questions

21. Are the terms exothermic and exergonic synonymous? Justify your answer with examples.
22. Life cannot exist in a completely closed system (no energy or matter comes into or out of the system).
 - a. Explain why this is true based on the Second Law of Thermodynamics.
 - b. The planet Earth is not a closed system. Ultimately, what is the source of all energy for life on Earth?
23. Consider a process where the increase in entropy of the system is exactly equal to the decrease in entropy of the surroundings. Would that process be spontaneous? Justify your reasoning.